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Inferential techniques for soil depth determinations Part II: Artemisia filifolia torr. (sand sagebrush)

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The objective of this work was to determine the reliability of a desert shrub, ARTEMISIA FILIFOLIA (sand sagebrush) as an indicator of soil depth. Near Lake Powell, Arizona/Utah; Hurricane, Utah; and St. George, Utah, more than 480 soil-depth-to-bedrock measurements were made in A. FILIFOLIA communities, in transitional, mixed communities, and in adjacent plant communities that did not contain A. FILIFOLIA. It was learned that the presence of ARTEMISIA FILIFOLIA reliably indicates that the depth of the soil mantle over the bedrock is greater than 1 meter.

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PREFACE

We thank Dr. Jack N. Rinker, Mr. M. B. Satterwhite, and Miss Judy Ehlen for their critical review of the manuscript, and Dr. Thomas Eastler, and Messrs. Thomas Currin and Robert Reese for their field assistance.

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INTRODUCTION

The use of vegetation/species as "indicators" is well documented in the scientific literature. Ramenskii,[1] Colwell and Olson,[2] Whittaker,[3] Billings,[4] Treiber and Krusinger,[5] and many others have documented the successful utilization of plants as indicators of various environmental conditions. Billings has said that ". . . . vegetation is a delicate integrator of environmental conditions and can be used as an indicator of such conditions.... It is difficult to express the environmental indications of vegetation in physical terms. Every vegetational stand is reflective of its past and present total environment. . . . Vegetation can indicate past environmental conditions or events . . . . ; vegetation can tell us much about soils conditions . . . .; physical structure . . . .; vegetation is then a sensitive environmental indicator . . . . . No instrument has ever been devised, or probably ever will be, that is as sensitive as vegetation."[6]

However, proposed indicators must be tested, and their reliability established. In their study of soil, as a factor influencing plant distribution on salt desert in Utah, Gates, Stoddart, and Cook[7] found that some previously proposed indicator species of specific soil characteristics were unreliable. However, in some instances they can be used for imposing upper limits, and establishing averages to be expected for certain soil factors. Because the distribution of a taxon is a function of its genetic and ecological tolerance, the factor(s) limiting its distribution can vary near the extremes of its geographical range. For example, the distribution of a taxon may be limited at one extreme of its geographic range by temperature, at another extreme by the availability of moisture, and at still another extreme by one or more edaphic conditions. These considerations must be taken into account in the application and use of plant communities or plant species as indicators of terrain conditions.

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[1] L. G. Ramenskii, *Vvedenie Vkompleksnoe Pochvenno-Geobotanichetkoe Issledovanie Zemel* (Introduction to the Complex Soil, Geobotanical Investigation of the Earth), Moscow, 1938.

[2] R.N. Colwell and D. L. Olson, *"Thermal Infrared Imagery and Its Use in Vegetation Analysis by Remote Aerial Reconnaissance," Symposium on Remote Sensing of Environment, 3rd Proceedings*, University of Michigan Institute of Science and Technology, 1965, pp. 607-621.

[3] R. H. Whittaker, *Communities and Ecosystems*, Macmillan Co., New York, 1970.

[4] W. D. Billings, *Plants, Man and the Ecosystem*, Wadsworth Publishing Co., Inc., Belmont, California, 1970.

[5] M. Treiber and A. E. Krusinger, *Inferential Techniques for Soil Depth Determinations, Part I: Coleogyne Ramosissima Torr. (Black-Brush)*. U. S. Army Engineer Topographic Laboratories, Ft. Belvoir, VA, Research Note, ETL-0036, November 1975, AD-A024 355.

[6] W. D. Billings, *Op.cit.*

[7] D. H. Gates, L. A. Stoddart, and C. W. Cook, "Soil as a factor influencing plant distribution on salt desert of Utah" *Ecol. Monogr.* 26 (2), 1956, pp. 155-175.

During preliminary field investigations in support of the Lake Powell Project by the Center for Remote Sensing (USAETL-RI-CRS), Research Institute, U. S. Army Engineer Topographic Laboratories, the feasibility of using plant species as indicators of terrain conditions was established, and a list of potential indicator species of the depth of soil to bedrock and soil type was compiled. The following species were identified as potential indicators:

Artemisia filifolia Torr.	*Juniperus osteosperma* (Torr.) Little
Coleogyne ramosissima Torr.	*Pinus edulis* Engelm.
Ephedra viridis Coville	*Tamarix pentandra* Poll.

The occurrence of *Coleogyne ramosissima* (Black-Brush) has been established as a reliable indicator of soil depths of less than 1 meter to bedrock.[8]

The present study was undertaken to describe and to establish the reliability of *Artemisia filifolia* as an indicator of soil depth to bedrock in northern Arizona and southern Utah.

STUDY AREAS AND METHODS

During 1973 and 1974, vegetation sampling and soil depth measurements were completed in three study areas in Utah and Arizona (Fig. 1). The study areas were characteristically in sandy soils on open plains of the:

1. Colorado River Plateau, in southeastern Utah (Kane County) and north central Arizona (Coconino County), adjoining Lake Powell.

2. Dixie Corridor, 4.8 km west of Hurricane, Washington County, Utah on Route 17 (Fig. 2).

3. Dixie Corridor, 4 km northwest of St. George, Washington County, Utah, on Route 18.

The study areas will hereafter be referred to as "Lake Powell," "Hurricane," and "St. George," respectively. During this investigation, 18 permanent test sites were maintained jointly by Brigham Young University and the U.S. Army Engineer Topographic laboratories at the Lake Powell study area (Fig 2). Two additional sites, Hurricane and St. George, were selected to test the reliability of *A. filifolia* as an indicator.

[8] M. Treiber and A. E. Krusinger, *Inferential Techniques for Soil Depth Determinations, Part I: Coleogyne Ramosissima Torr. (Black-Brush).* U. S. Army Engineer Topographic Laboratories, Fort Belvoir, VA, Research Note, ETL-0036, November 1975, AD-A024355.

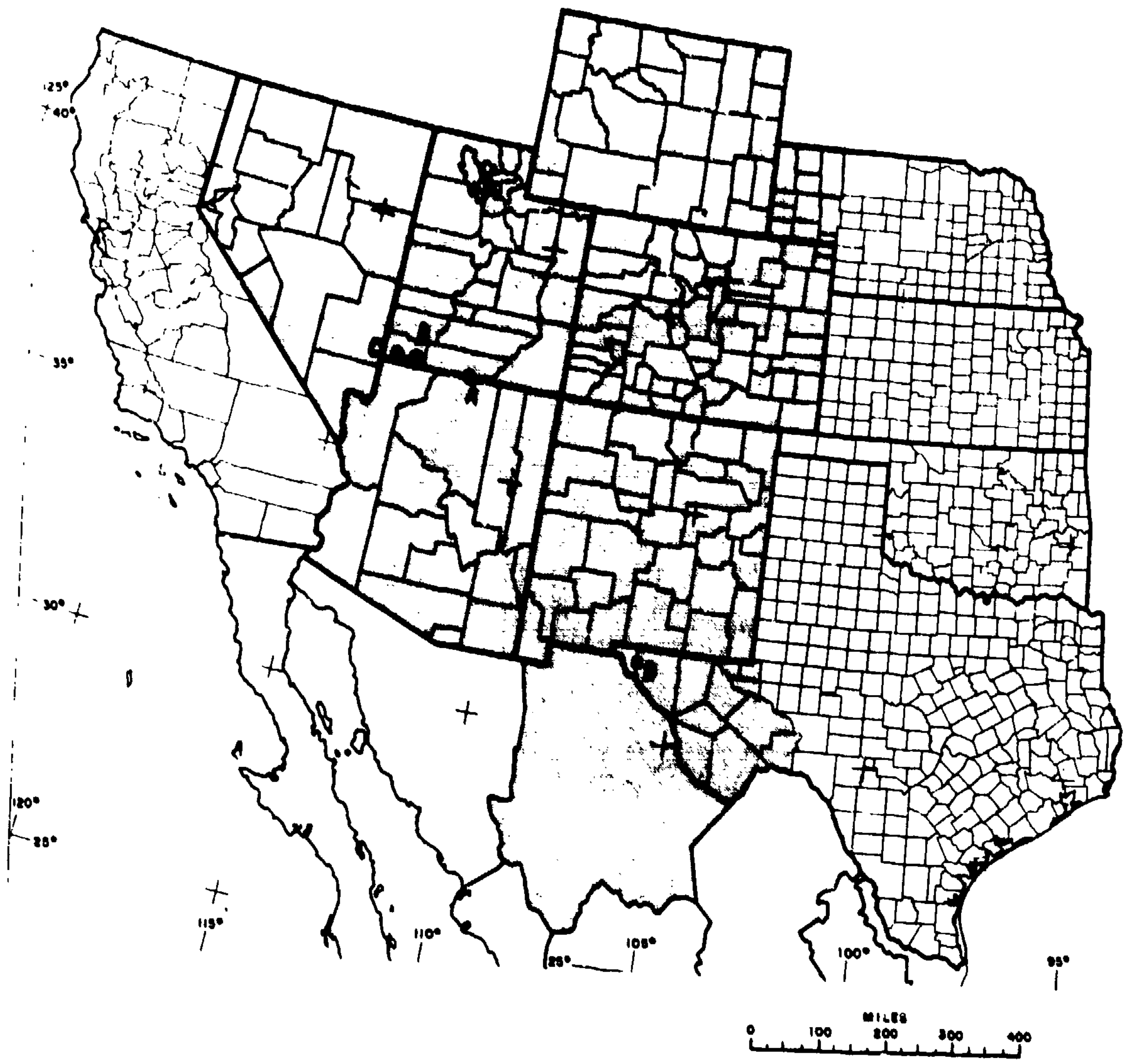

Figure 1. Map of Southwestern U. S. showing study areas: (*A*), Lake Powell, AZ, UT; (*B*), Hurricane, UT; (*C*), St. George, UT. Also shown is Ft. Bliss, TX (*D*), where collaborative data were acquired. The shaded area represents, by state, the known distribution of *A. filifolia*.

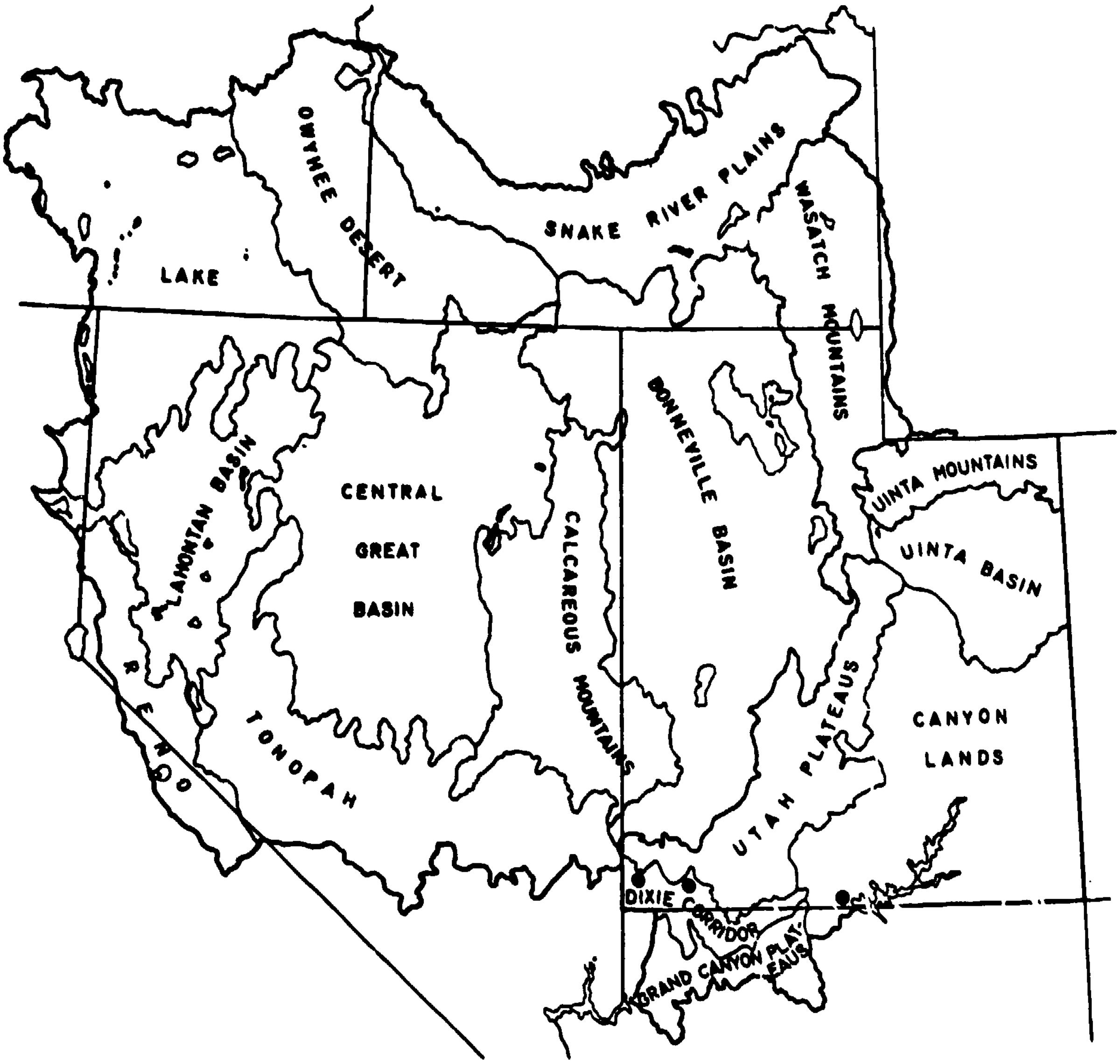

Figure 2. Map of the Intermountain Region showing the floristic sections (Nevada, Utah, parts of California, Oregon, Idaho, Wyoming, and Arizona). Study areas are indicated by black dots. (Taken from Cronquist, et al, 1972).

The vegetation in the study areas, when considered in light of Woodbury's generalized Profile of Vegetation Zones in Utah[9] (Fig. 3), spans four zones, namely the pigmy conifers, sagebrush, desert shrub, and creosote brush. More recently, Cronquist et al,[10] recognized 16 floristic sections in the Intermountain Region. The Hurricane and St. George sites are in the Dixie Corridor section, and the Lake Powell site is in the Canyon Lands section (Fig. 2). Within the Dixie Corridor section, lowlands of the area, below the 1,220-meter (4,000 ft) contour, are covered by the Mojavean Creosote bush (*Larrea tridentata)* community. Other common shrubs in this region are sand sagebrush (*A. filifolia)*, bur sage (*Ambrosia dumosa)*, Krameria (*Krameria parviflora)*, and, in moist habitats, mesquite (*Prosopsis juliflora)*. The Canyon Lands section is characterized by a broad desert plain broken by deep canyons, structural upwarps, and laccolithic mountains. Floristically, the Canyon Lands section is the richest portion of the Intermountain Region for endemic species. Within the Canyon Lands section, Woodbury recognized the following vegetation zones: ponderosa pine, pigmy conifer, sagebrush and desert shrub.[11] The vegetation throughout this region is subjected to hydrologic as well as thermal stress over much of the year. In addition, there is fierce competition for nutrients and suitable germination sites, both interspecifically and intraspecifically, and as such, each individual plant has a strict niche requirement that must be satisfied. There are many factors that place a limit on the successful colonization by a specific taxon, e.g. soil depth, soil type, water availability, nutrient requirements, temperature, propogule dissemination mechanism, etc. A discussion of the interaction of these parameters, as related to species distribution, is beyond the scope of this report; therefore, reference is made to Odum,[12] Whittaker,[13] Fuller and Carothers,[14] and Foster.[15]

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[9] A. M. Woodbury, "Distribution of Pigmy Conifers in Utah and Northeastern Arizona," *Ecology* 28 (2), 1947, pp. 113-126.

[10] A. Cronquist, A. H. Holmgren, N. H. Holmgren, and J. L. Reveal, *Intermountain Flora*, Hafner Publishing Co., Inc., New York, 1972.

[11] A. Cronquist, A. H. Holmgren, N. H. Holmgren and J. L. Reveal, *Intermountain Flora*, Hafner Publishing Co., Inc., New York, 1972.

[12] E. P. Odum, *Fundamentals of Ecology*, 3rd Ed., W. B. Saunders Co., 1971.

[13] R. H. Whittaker, *Communities and Ecosystems*, Macmillan Co., 1970.

[14] H. J. Fuller and Z. B. Carothers, *The Plant World*, 4th Ed., Holt, Rhinehart and Winston, Inc., 1963, p. 488.

[15] R. H. Foster, *Distribution of the Major Plant Communities in Utah*, unpublished dissertation, Brigham Young University, 1968.

VEGETATION BELTS OF UTAH

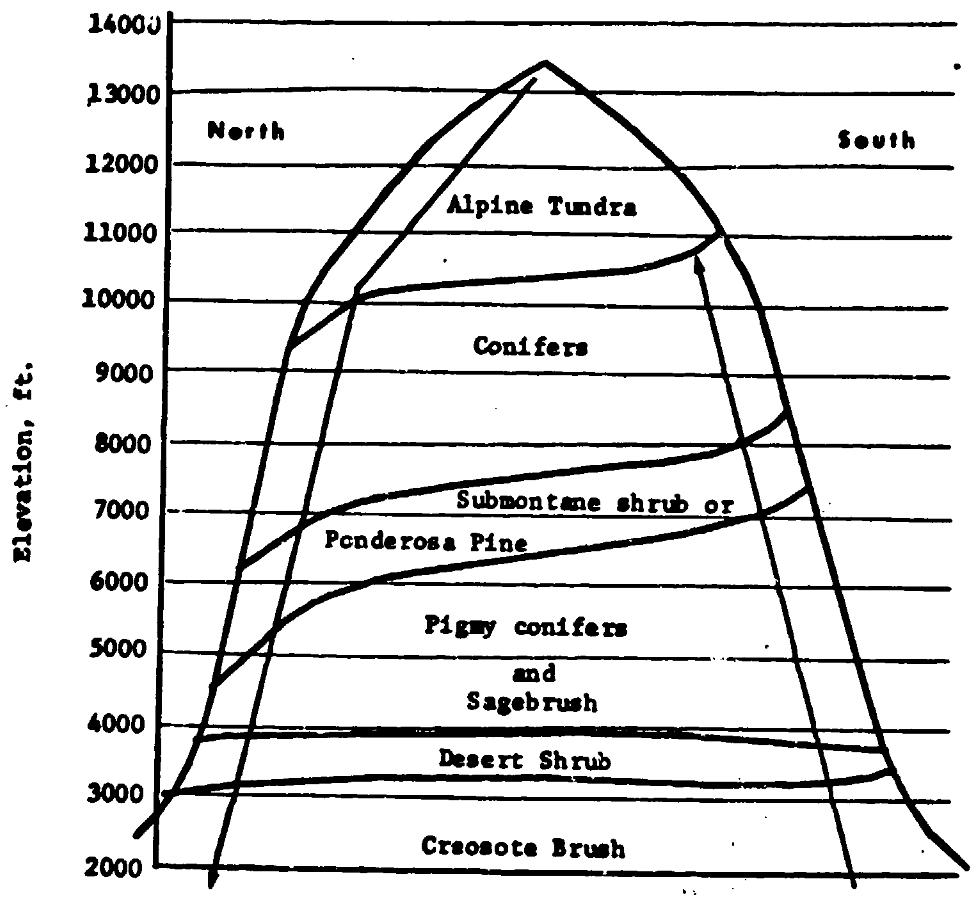

Figure 3. Generalized Profile of Vegetation Belts or Zones in Utah (After Woodbury, 1947).

The Lake Powell study area is in a high desert environment with an average annual rainfall of 12.1 mm (4.78 inches), based on an 8-year period. Table 1 summarizes the figures for maximum temperatures, minimum temperatures, precipitation, and lake surface water temperatures at Wahweap, Utah. No comparable data are available for either the Hurricane or St. George study sites.

Soil depth measurements were made either along line transects that were set up across boundaries between *A. filifolia* and adjacent communities or at random within the zones defined below. Each transect was divided into five arbitrary zones (*A* through *E*), defined in relation to the boundary, zone *C*, between the two plant communities.

Zone *C*, the boundary zone, consisted of a 5-meter-wide swath, the center of which was defined as the last occurrence of *A. Filifolia.* The last occurrence of *A. filifolia* was used as the reference point for all measurements, inside and outside of *A. Filifolia* communities. Two zones (*D* and *E*) were defined within *A. filifolia* communities. Zone *D* lay between 2.5 and 8.0 meters from the center of the boundary zone (*C*), and zone *E* lay greater than 8 meters from the center of the boundary zone. Two zones (*A* and *B*) outside *A. filifolia* communities were similarly defined. Zones *B, C,* and *D* constitute an ecotone, the width of which is 16 meters. These zones were defined to facilitate the investigation of changes in the depth of soil to bedrock across ecotones between *A. filifolia* and adjacent communities. In each of these zones, depth measurements were made by digging soil pits or by using a soil depth probe. Soil depth to bedrock was defined as the depth of refusal of the shovel or depth probe.

The maximum measureable soil depth was 180 centimeters (cm), and all soil depths greater than 180 cm were arbitrarily assigned a value of 180+ cm. Soil depth in areas where plants were found growing in crevices in exposed bedrock was designated as 0 cm.

In conjunction with the field work, aerial photography was taken. with two film types at four scales. The film types examined were color, Ektachrome MS 2448, and Panchromatic, Double-X 2405 with Wratten 12 filter. Both film types were studied at scales of 1:500, 1:3,575, 1:5,750, and 1:9,700.

RESULTS

At the sites included in this study, *Artemisia filifolia* consistently occurred in soils where the depth to bedrock was greater than 1 meter. The relative frequency distribution of all depth measurements shows that within *A. filifolia* communities (zone *E*), all soil depth to bedrock measurements exceeded 100 cm, and no soil depths less than 100 cm were recorded (Table 2). In the ecotone (zones *B, C,* and *D*), 82.2 percent of the depths measured were less than 100 cm, and 17.8 percent were equal to or greater than 100 cm. Soil depths in these transitional zones were highly variable. All measurements outside of

TABLE 1. LAKE POWELL WEATHER AND LAKE ELEVATION
(Based on 8 years of Records at Wahweap)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
MAXIMUM TEMPERATURE (Degrees Fahrenheit)												
Average	45	53	61	72	82	90	97	94	88	77	59	45
Record	68	72	81	92	97	115	108	106	100	93	74	67
MINIMUM TEMPERATURE (Degrees Fahrenheit)												
Average	24	31	36	46	53	62	71	69	61	50	38	25
Record	-4	16	22	28	38	47	53	55	36	32	21	3
PRECIPITATION (Inches)												
Average	.16	.30	.37	.36	.51	.13	.23	.79	.72	.33	.34	.53
Record	.45	.62	1.26	1.14	1.89	.33	1.45	1.52	1.31	.82	.98	1.17
LAKE SURFACE WATER TEMPERATURE (Degrees Fahrenheit)												
Wahweap	44	46	55	55	64	72	79	79	73	65	60	50
Bullfrog	47	46	52	54	64	70	76	80	76	69	62	53

A. filifolia (zone *A*) were less than 100 cm, but were expected to be shallow since the adjacent community was frequently dominated by *Coleogyne ramosissima*, an indicator of shallow soil depth.[16]

Tables 2 and 3 show the relative frequency distribution and the frequency distribution of soil depth measurements, respectively, and the data of Table 2 are represented graphically in Figure 4. Figure 4 is a set of three histograms that represent the distribution of soil depth in three major zones: (1) within *A. filifolia*, zone *E*; (2) the 16-meter ecotone, zones *B, C,* and *D*; and (3) outside *A. filifolia*, zone *A*.

Figure 5 is a summary of all soil depth to bedrock measurements, by zones (*A* through *E*), where *E* summarizes measurements performed within *A. filifolia* communities more than 8 meters inside the boundary zone center line, and *A* summarizes measurements of soil depth performed in adjacent communities at a distance greater than 8 meters outside of the boundary zone center line. The summary graphs for the ecotone, *B, C,* and *D*, demonstrate effectively the transitional nature of soil depths between *E* and *A*. Note that both *E* and *A* are highly skewed; *E* is skewed positively, toward greater depths, and *A* is skewed negatively, toward shallow depths (figure 6). All data, by site, are presented in Appendix *A*.

In areas where *A. filifolia* occurs as scattered individuals, soil depth measurements were found to be variable, with a range in soil depths approximating the values encountered in the transitional zones.

Independent of our studies, M. B. Satterwhite (personal communications) reports similar results from studies in the Fort Bliss, Texas, area.

CONCLUSIONS

Artemisia filifolia is a reliable indicator of the fact that the depth of the soil mantle over the bedrock is greater than 1 meter. Preliminary analysis of aerial photography of the Lake Powell, Hurricane, and St. George study sites indicates that *A. filifolia* can be discriminated from other desert shrubs by remote sensing techniques. Therefore, the ability to discriminate *A. filifolia* enables the investigator to derive terrain information, namely soil depth to bedrock, from analysis of aerial photography.

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[16] M. Treiber and A. E. Krusinger, *Inferential Techniques for Soil Depth Determinations, Part I: Coleogyne Ramosissima Torr. (Black-Brush)*. U. S. Army Engineer Topographic Laboratories, Fort Belvoir, VA, Research Note, ETL-0036, November 1975, AD-A024 355.

Artemisia filifolia can be discriminated on black and white photography by the feathery texture of the individual shrub; however, large scale (1:1500) imagery is required (Fig. 6). *A. filifolia* is detected mainly on the basis of its gray-green color, and therefore color photography should be used for this purpose (Fig. 7).

On color photography, stands of *A. filifolia* were readily identifiable at all four scales. On panchromatic photography, the reliability of identification and delineation of *A. filifolia* was greatly reduced, particularly at 1:9,700.

Sand sagebrush (*A. filifolia*) is only one of many plant species that are reliable indicators that can be exploited in the extration of terrain data. Other possible "species/vegetation indicators" should be investigated and tested to establish their reliability as indicators of specific soil characteristics, as well as other environmental characteristics.

TABLE 2. Relative Frequency Distribution of Soil Depth Measurements

Depth Interval (cm)	Percent Within A. filifolia (X >8 m)	Percent in Ecotone (16 m)	Percent Outside A. filifolia (X >8 m)
0-9	0.0	18.5	72.7
10-19	0.0	21.5	17.3
20-29	0.0	12.6	8.2
30-39	0.0	7.4	0.9
40-49	0.0	5.2	0.9
50-59	0.0	1.5	0.0
60-69	0.0	4.4	0.0
70-79	0.0	3.7	0.0
80-89	0.0	5.2	0.0
90-99	0.0	2.2	0.0
100-109	2.1	7.4	0.0
110-119	4.2	5.2	0.0
120-129	4.6	3.0	0.0
130-139	5.9	1.5	0.0
140-149	10.9	0.7	0.0
150-159	7.2	0.0	0.0
160-169	15.6	0.0	0.0
170-179	13.4	0.0	0.0
180-∞	36.1	0.0	0.0
19 intervals	100.0	100.0	100.0

TABLE 3. Frequency Distribution of Soil Depth Measurements

Depth Interval (cm)	Frequency Within A. filifolia (X >8 m)	Frequency in Ecotone (16 m)	Frequency Outside A. filifolia (X >8 m)
0-9	0	25	80
10-19	0	29	19
20-29	0	17	9
30-39	0	10	1
40-49	0	7	1
50-59	0	2	0
60-69	0	6	0
70-79	0	5	0
80-89	0	7	0
90-99	0	3	0
100-109	5	10	0
110-119	10	7	0
120-219	11	4	0
130-139	14	2	0
140-149	26	1	0
150-159	17	0	0
160-169	37	0	0
170-179	32	0	0
180-∞	86	0	0
19 intervals	238	135	110

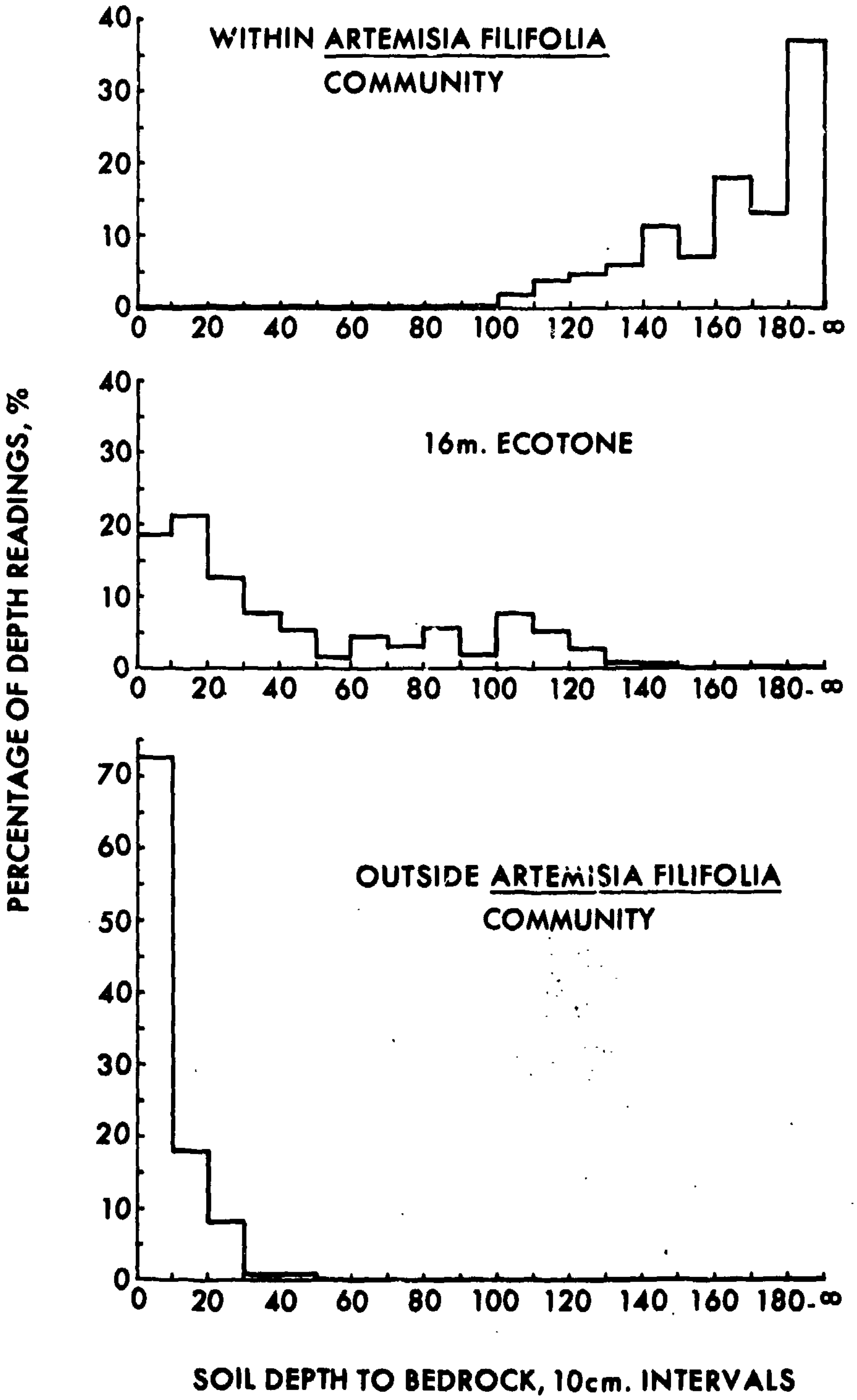


Figure 4. Histograms of Relative Frequency of Soil Depth Measurements.

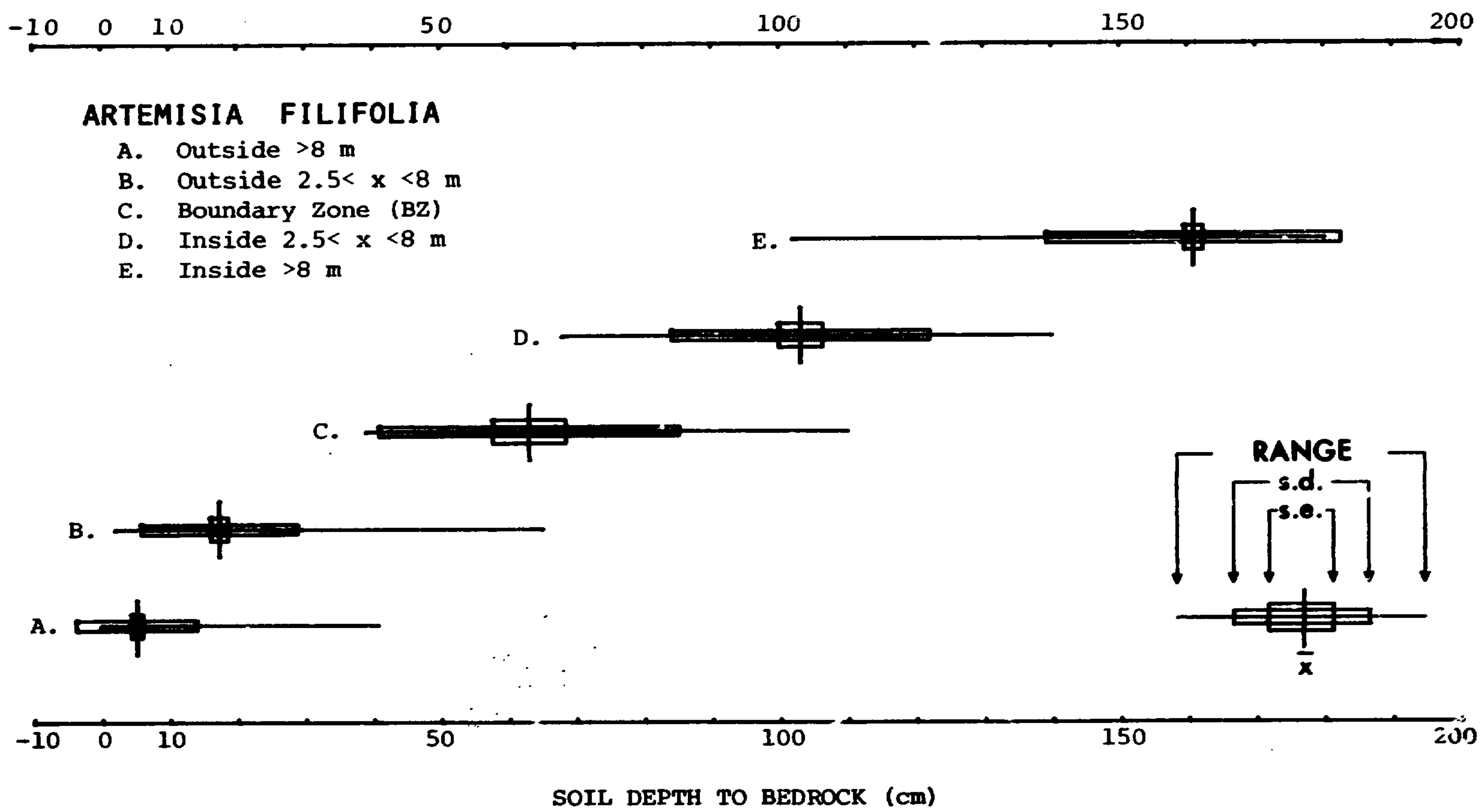


Figure 5. Summary statistics for soil depth measurements along transects intersecting stands of *A. filifolia.* The boundary zone (BZ) is a 5 meter wide swath transitional between stands of *A. filifolia* and adjacent communities. The center of the BZ is defined by the last occurrence of *A. filifolia.* All measurements, outside and inside stands of *A. filifolia*, are made with respect to this point.

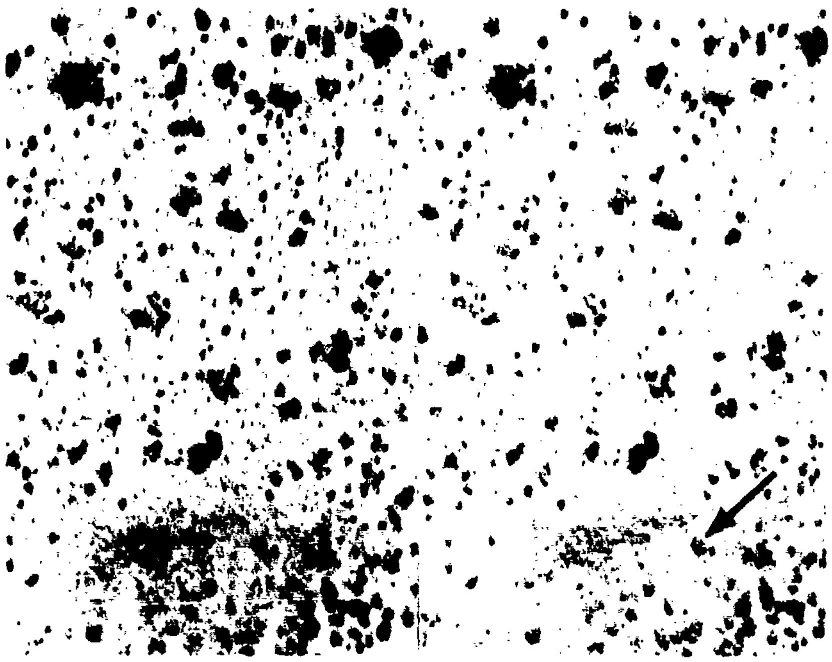
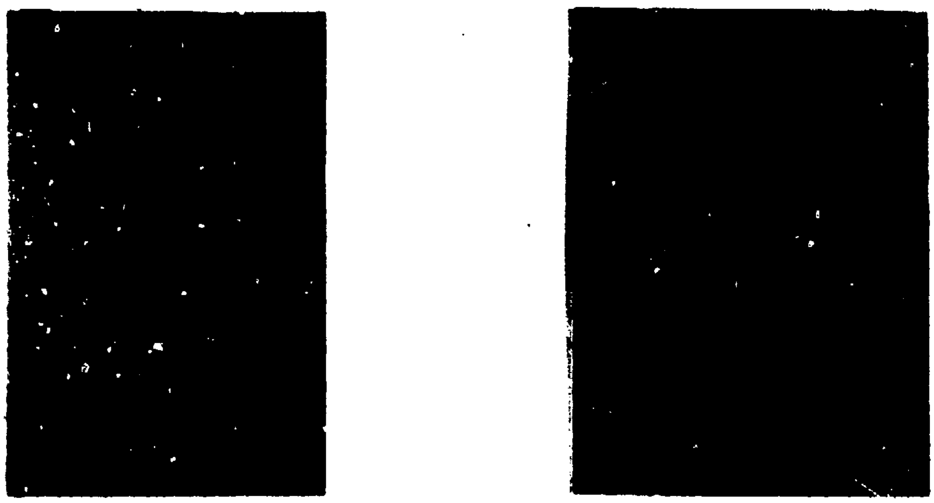


Figure 6. Stereogram of vertical, aerial, black and white photographs, scale 1:500, of *Artemisia filifolia*. The arrow points to an individual plant of *A. filifolia*.

Fig. 7. Color photographs of *Artemisia filifolia* depicting the gray-green color characteristic of the foliage of this species; A) close-up of an individual plant, B) stereogram of an *A. filifolia* community, and C) stereogram of vertical, aerial, color photographs, scale 1:3,800 of an *A. filifolia* community. The arrows in B and C point to stands of *A. filifolia*.



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APPENDIX A. SOIL DEPTH MEASUREMENTS
(in centimeters)

Site No.	Within Artemisia filifolia		Boundary Zone	Outside Artemisia filifolia	
	X >8 m	2.5 m <x≤ 8 m	(5 m)	2.5 m <x≤ 8 m	X >8 m
T-1	150	68	68	21	7.6
	130	75	42	3	16.5
	140	75	42	17	3.8
	120	82	45	6	20.3
	123	82	62	16	3.8
	140	85	102	8	20.3
	140	87	110	14	38.0
	140	88		14	40.6
	140	89		22	15.3
	160	95		15	15.3
	170	68		9	12.0
	165	90		47	15.0
	170	105		8	15.0
	175	105		3	15.0
	180	109		12	17.0
	125	113		5	17.5
	138	113		7	21.0
	140	117		6	22.0
	145	119		16	22.0
	150	120		4	
	165	126		31	0 x 77
	160	130		8	
	160	129		14	
	160	123		10	
	150	107		26	
	130			24	
	168			6	
	175			30	
	180			13	
	180			17	
	130			3	
	113			19	
	119			17	
	109			14	
	122			24	
	131			10	
	142			17	
	120			17	
	110			16	
	115			7	
	121			8	
	112			8	
	113			3	
	124			15	
	126			5	
	110			26	

APPENDIX A. (Continued)

Site No.	Within *Artemisia filifolia*		Boundary Zone (5 m)	Outside *Artemisia filifolia*	
	X >8 m	2.5 m <x≤ 8 m		2.5 m <x≤ 8 m	X >8 m
T-1 (Cont'd)	109			9	
	107			35	
	130			16	
	130			20	
	112			19	
	122			11	
	109			18	
	116			13	
	119			27	
	135			9	
	140			30	
	150			15	
	133			21	
	125			6	
				23	
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				13	
				16	
				15	
				26	
Hurricane, Utah	>108 x 25				
GC-102	160	100	85	65	17.0
	156				17.5
	171				21.0
	175				22.0
	174				22.0
	179				
	180				
	180				
	165				
	164				
	170				
	167				
	180				
	156				
	161				
	175				
	180				
	180				

APPENDIX A. (Continued)

Site No.	Within Artemisia filifolia		Boundary Zone (5 m)	Outside Artemisia filifolia	
	X >8 m	2.5 m <x≤ 8 m		2.5 m< x≤ 8 m	X >8 m
GC-102 (Cont'd)	180				
	180				
	172				
	175				
	180				
	160				
	145				
	163				
	172				
	180				
	174				
BYU-2	170	92	68.5	51	20.3
	164			27	12.0
	163				15.0
	150				15.0
	180				15.0
	180				
	180				
	180				
	180				
	180				
	180				
St. George, Utah	145				
	132				
	102				
	157				
	180				
	125				
	162				
	171				
	153				
	136				
	141				
	130				
	160				
	156				
	145				
	130				
	160				
	154				

APPENDIX A. (Continued)

Site No.	Within Artemisia filifolia		Boundary Zone (5 m)	Outside Artemisia filifolia	
	X >8 m	2.5 m <x≤ 8 m		2.5 m <x≤ 8 m	X >8 m
GC-101		135	39	24.0	10.0
		100	41	26.0	12.5
		105	41	27.0	13.0
		107	47	28.0	17.5
		109	74	30.0	
		110	73	32.0	
		110	76	22.5	
		140	77	30.0	
				30.0	
				35.0	
Random	160				
	157				
	174				
	152				
	135				
	142				
	165				
	146				
	175				
	164				
	142				
	170				
	165				
	176				
	164				
	164				
	169				
	144				
	146				
	168				
	162				
	173				
	161				
	175				
	141				
	149				
	172				
	1?7				
	172				
	176				
	141				
	153				
	167				
	172				
	165				

APPENDIX A. (Continued)

Site No.	Within *Artemisia filifolia* X >8 m	Within *Artemisia filifolia* 2.5 m $<x\leq$ 8 m	Boundary Zone (5 m)	Outside *Artemisia filifolia* 2.5 m $<x\leq$ 8 m	Outside *Artemisia filifolia* X >8 m
Random (Cont'd)	161 163 158 169 167 174 173 146 144 141 175 167 164 173 177 144 157 153 170 >180 x 41				
No. of Observations (N)	238	35	17	83	110
Mean ($\bar{X}$)	160.9	103.1	63.1	17.3	5.2
Standard Deviation	21.6	18.9	22.1	11.5	8.9
Range	78.0	72.0	71.0	63.0	40.6
Standard Error (S.E.)	1.4	3.2	5.4	1.3	0.8

APPENDIX B

DESCRIPTION AND DISTRIBUTION OF *ARTEMISIA FILIFOLIA*

The following description and distribution of *Artemisia filifolia* Torr. is based on Kearney and Peebles.[17] Shrubs 25 to 150 cm: leaves alternate, linear-filiform less than 1 mm wide, entire or three parted; head small, discoid, usually very numerous, spicate, racemose, or panicled; pistillate outer flowers, without rays, sometimes present; achenes short, thick glabrous.

The distribution of *A. filifolia* is as follows: "Apache, Navajo, Coconino, Mohave, Graham, and Cochise Counties, Arizona; Nebraska and Wyoming to Nevada; Texas, and northern Mexico."[17]

Klingman states, as reported in Bovey,[18] that in the Continental United States, *A. filifolia* has a total acreage of 96 million acres. Schafer[19] reported that at least 100,000 acres in western Nebraska are almost useless for grazing because *A. filifolia* is toxic to sheep and cattle.

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[17] T. H. Kearney and R. H. Peebles, *Arizona Flora*, 2nd Ed., University of California Press, Los Angeles, California, 1969, pp. 938-941.

[18] R. W. Bovey, "Aerial applications of herbicides for control of sand sagebrush," *J. Range Management*, 1964, 17(5): pp. 253-256.

[19] N. E. Schafer, *Farming from the air*, Research Report, University of Nebraska, 1955, pp. 5-10.